

What to Do  
When the Weather Changes?  
Water Management  
Adaptation and Climate Change

Jay R. Lund and Tingju Zhu  
University of California, Davis

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and Stratus Consulting

<http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/>

# Overview

**Climate  
Changes**

**Floods**

**Other  
Changes**

**Droughts**



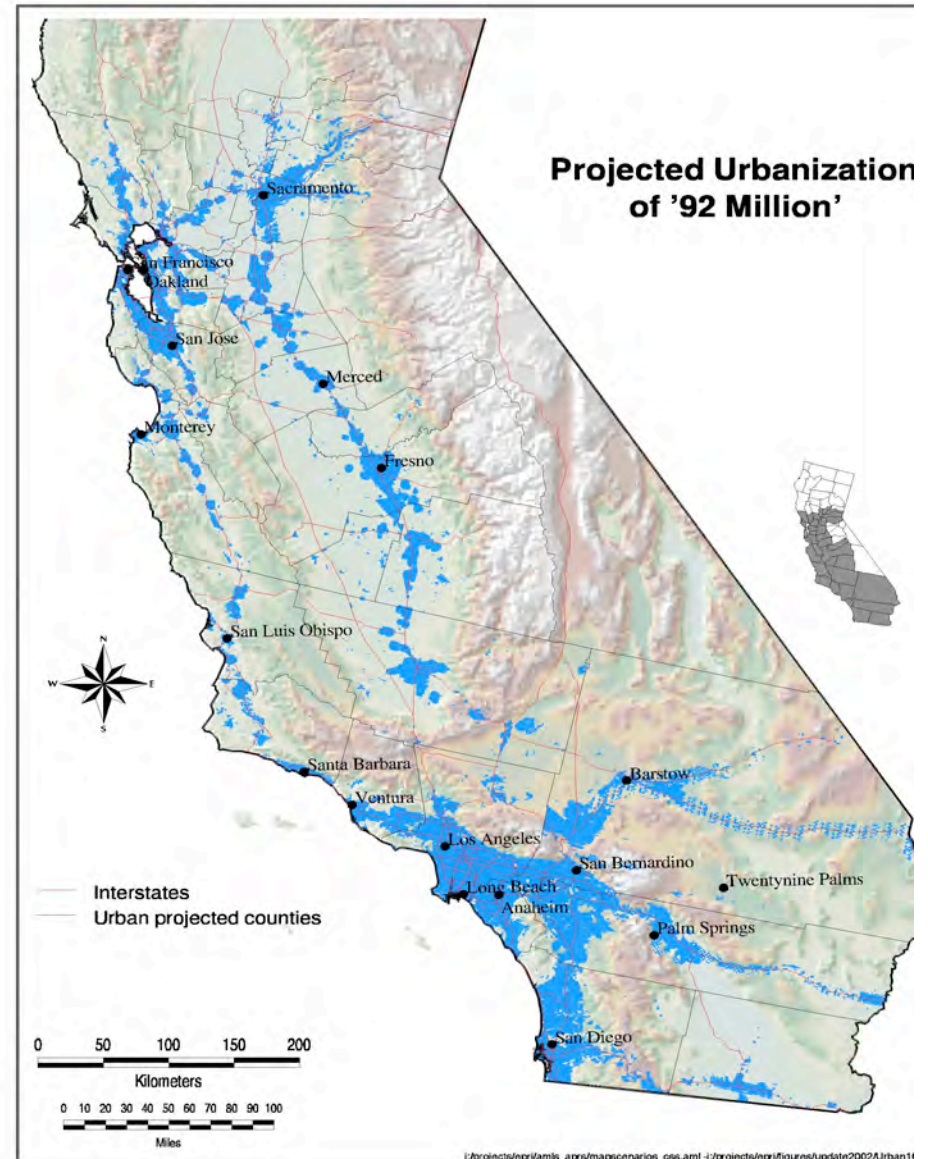
**Adaptations**

# Forms of Climate Change

1. Sea level rise
2. Climate warming
3. Climate oscillations
4. Multi-decade droughts
5. Other forms of change?

# Other Big Changes

1. Population growth
2. Land use
3. Social values
4. Economic well-being
5. Crop prices, yields, etc.
6. Others?



John Landis, UCB, estimates 2002

# Adaptation Studies for Climate Change

- Planning studies more than “impact” studies
- Allow and explore substantial adaptation, preferably with multiple options
- Use future population, land use, and economic conditions
- For complex systems, some optimization will be required
- Interpretation and limitations



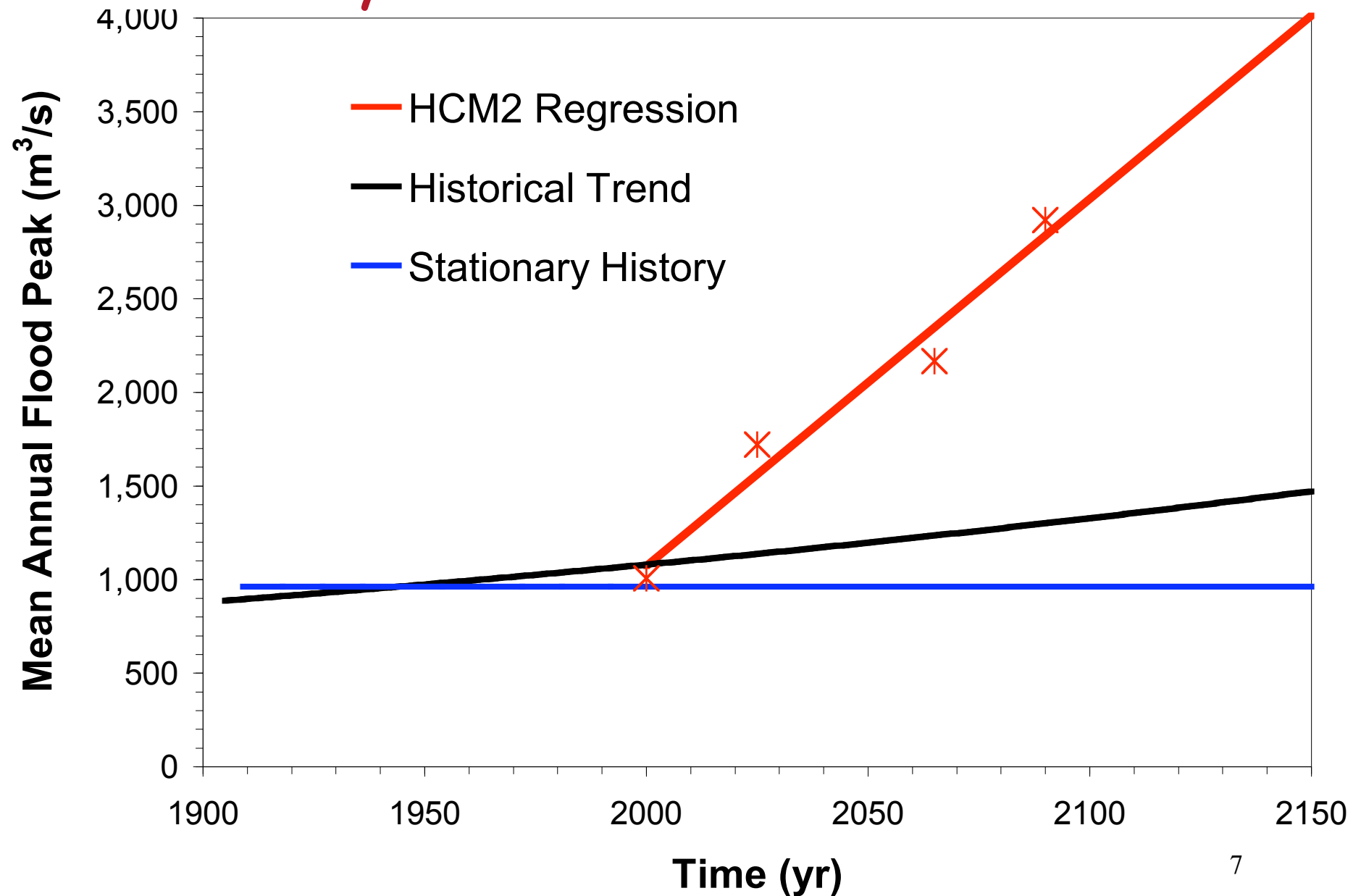
# Flooding on the Lower American River



## Climate Change and Urbanization



# Three-Day Peak Inflows at Folsom Lake

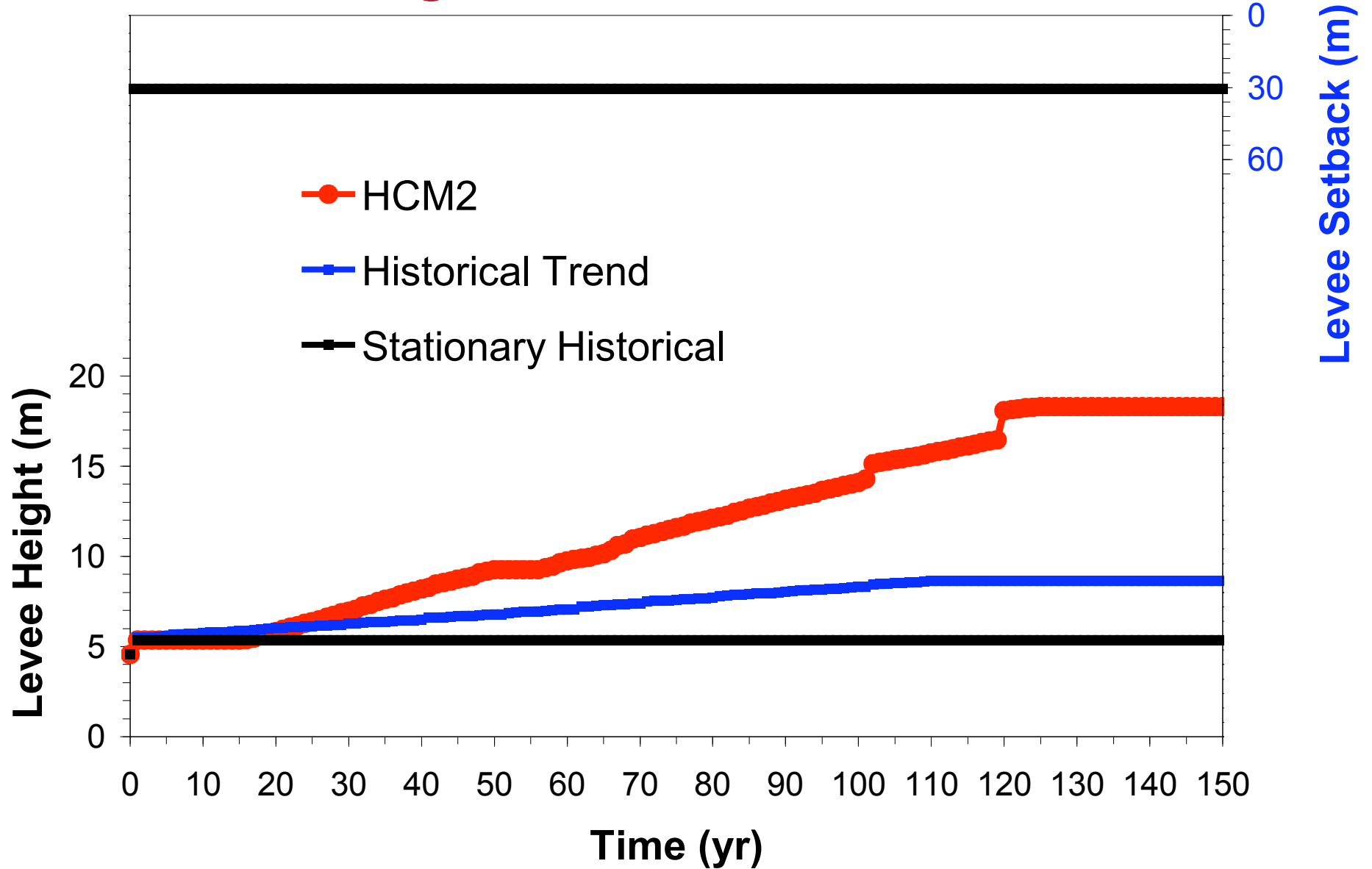


# Method

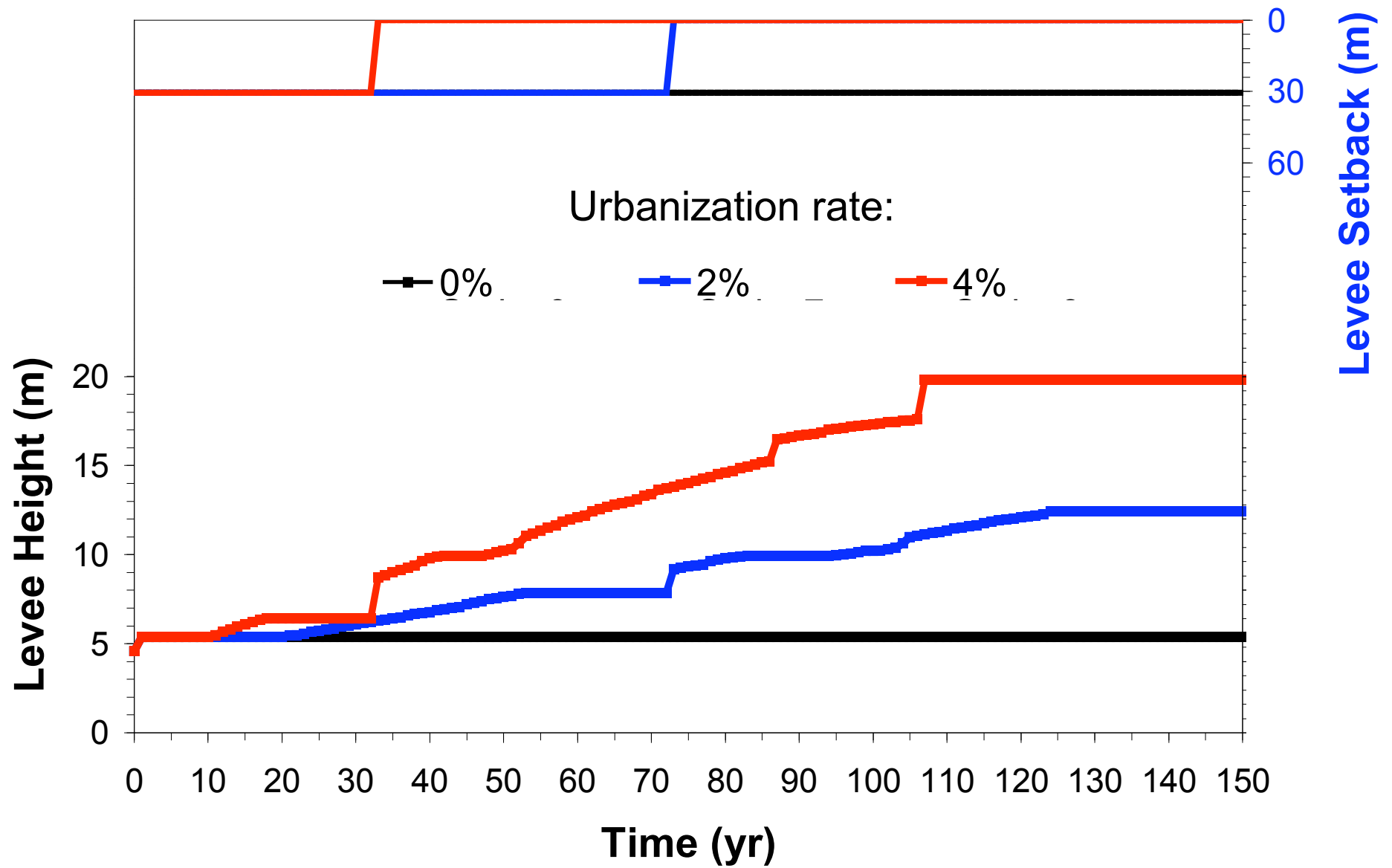
- Optimize levee heights & setbacks over time
- Minimize average total cost of:
  - flood damage and frequency
  - levee construction
  - lost urban and floodplain land value
- Considers changing flood probabilities
- Changing urban land and flood damage values – 150 year time frame.



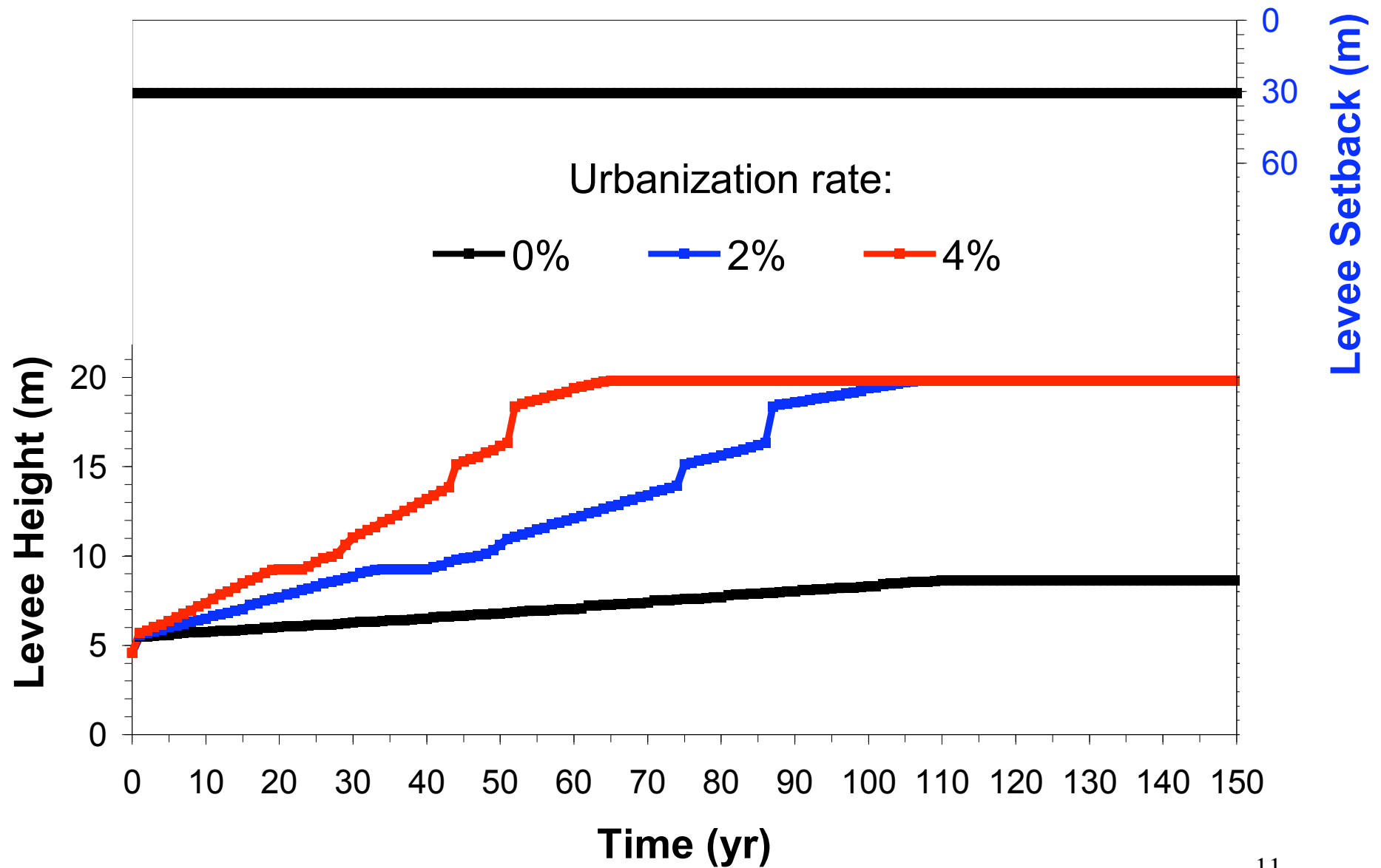
# Climate Change Alone Without Urban Growth



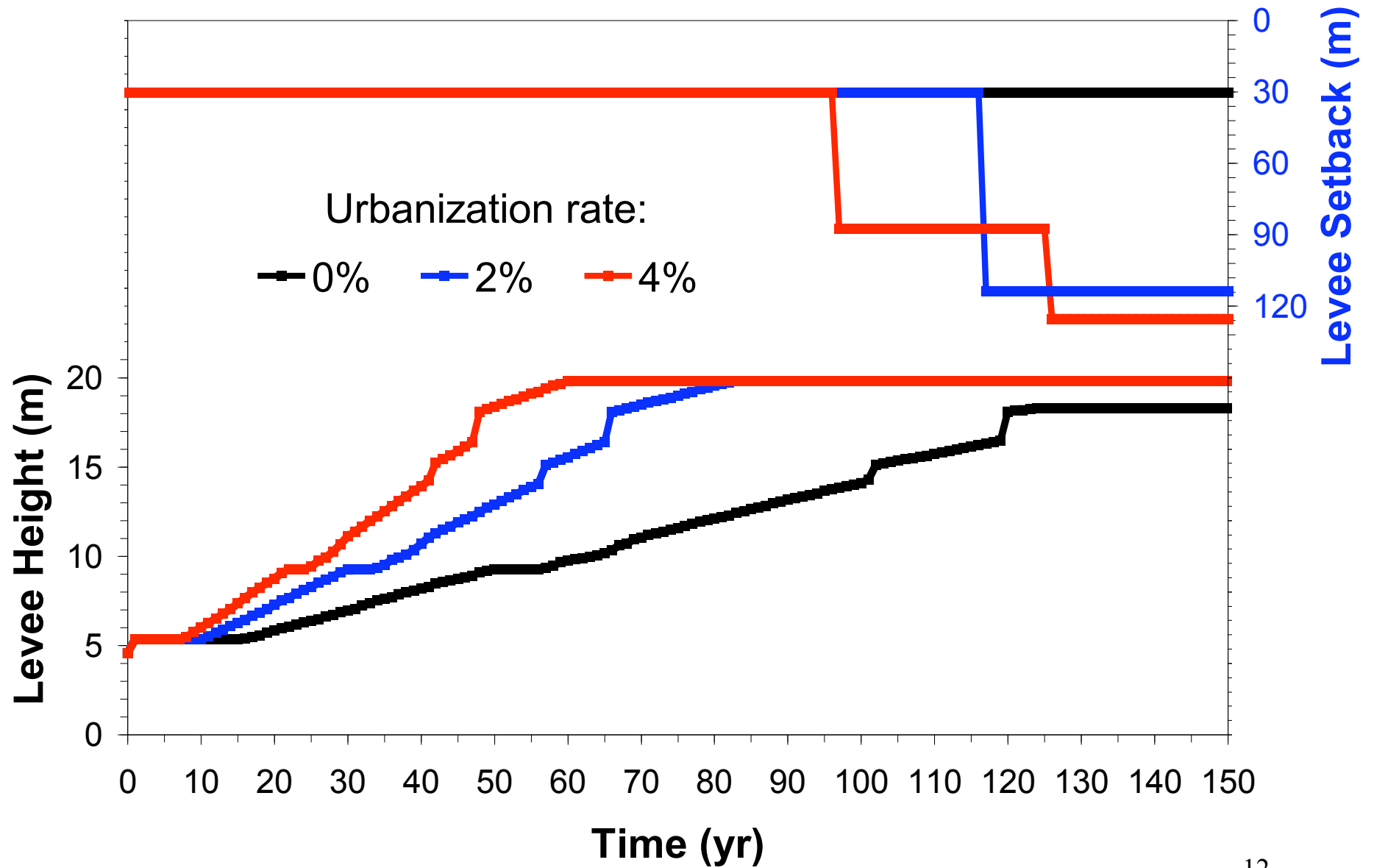
## Urban Growth Alone



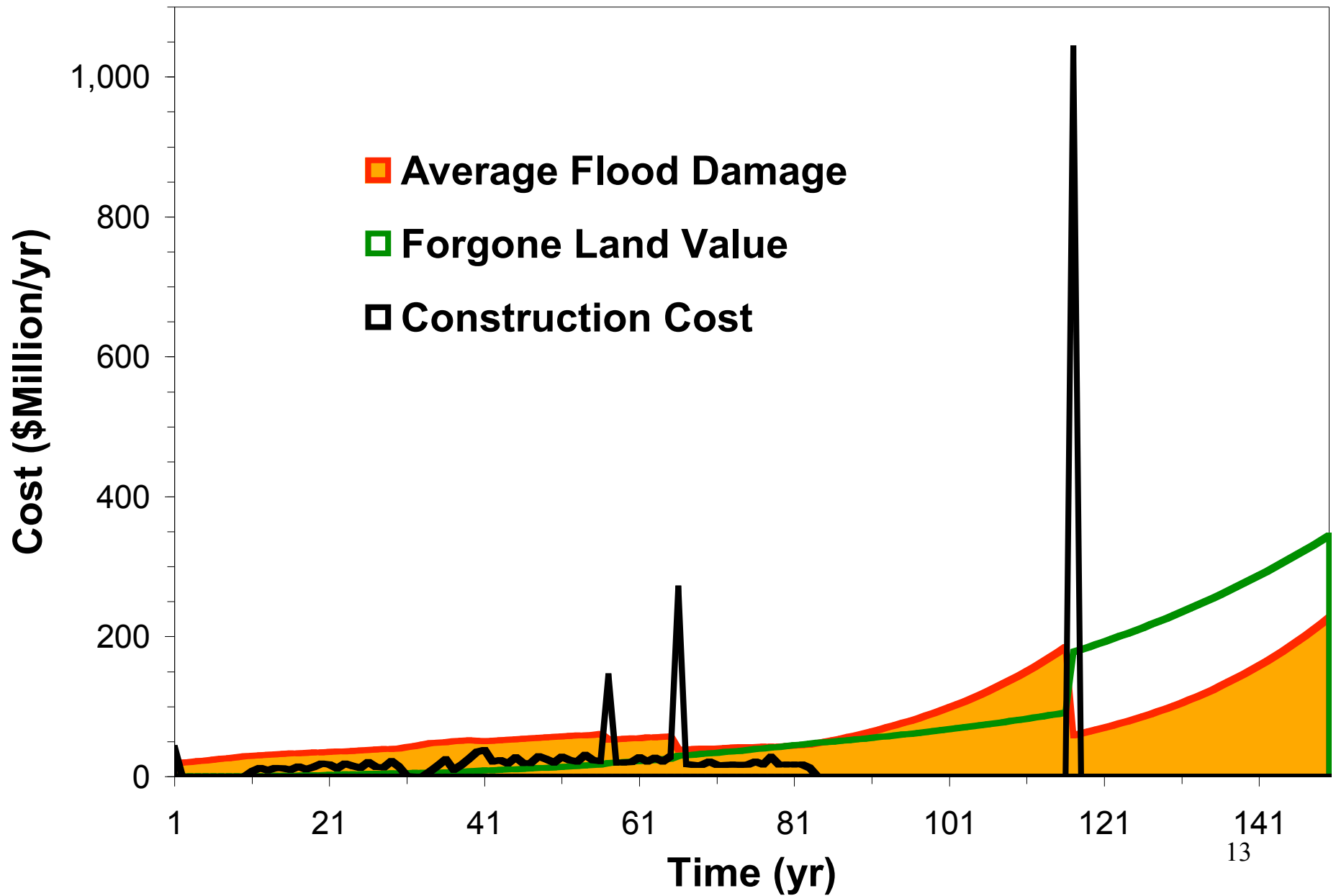
# Combined Effects with Historical Trend in Floods



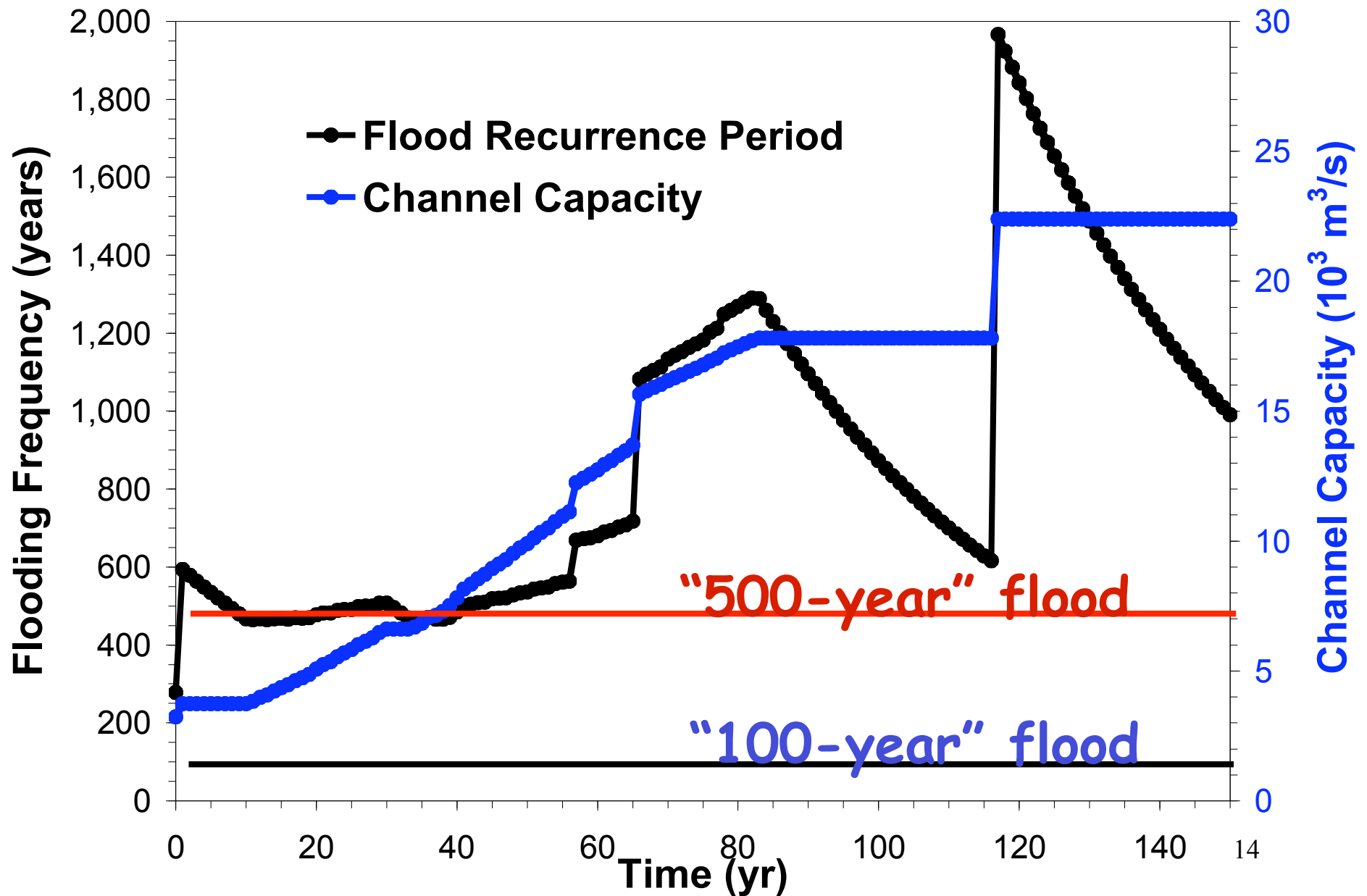
## Combined Effects with HCM2 Scenario



## Costs: 2% Urbanization & HCM2 Climate



## 2% Urbanization & HCM2 Hydrology





# Observations

- 1) Climate changes or urbanization alone can be accommodated by raising levees
- 2) Combined effects can raise levees and increase levee setbacks
- 3) Adding loss of life accelerates levee raising and floodway widening
- 4) Adding climate change uncertainty could slow or speed adaptation
- 5) Non-levee adaptations are also likely
- 6) Raising American River levees & perhaps widening floodway might be desirable

# Flood Control Conclusions

- 1) People and societies adapt all the time.
- 2) Combined effects of climate change and other factors are important for adaptations
- 3) Increasing Central Valley flooding problems
  - Continued urbanization
  - Wet climate warming & apparent flood trends
  - Other tributaries have similar problems
  - Limits of levees and levee heights alone
- 4) “100-year” flood planning is a bad wager<sub>16</sub>

# Adaptation Studies for Climate Change

- Planning studies more than “impact” studies
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# Water Supply Adaptation to Climate Warming

- 2100 water availability, population, land use, and water demands
- Water management adaptation to climate warming extremes

Supported by California Energy Commission, PIER

## Real work done by

Dr. Tingju Zhu

Stacy K. Tanaka

Dr. Manuel Pulido

Inês Ferreira

Dr. Kenneth W. Kirby

Brad D. Newlin

Melanie Taubert

Matthew D. Davis

Kristen B. Ward

Brian J. Van Lienden

Mark Leu

Prof. Richard Howitt

Dr. Marion W. Jenkins

Dr. Siwa M. Msangi

Randall Ritzema

Dr. Andrew J. Draper

Prof. Guilherme Marques

Dr. Arnaud Reynaud

Sarah Null

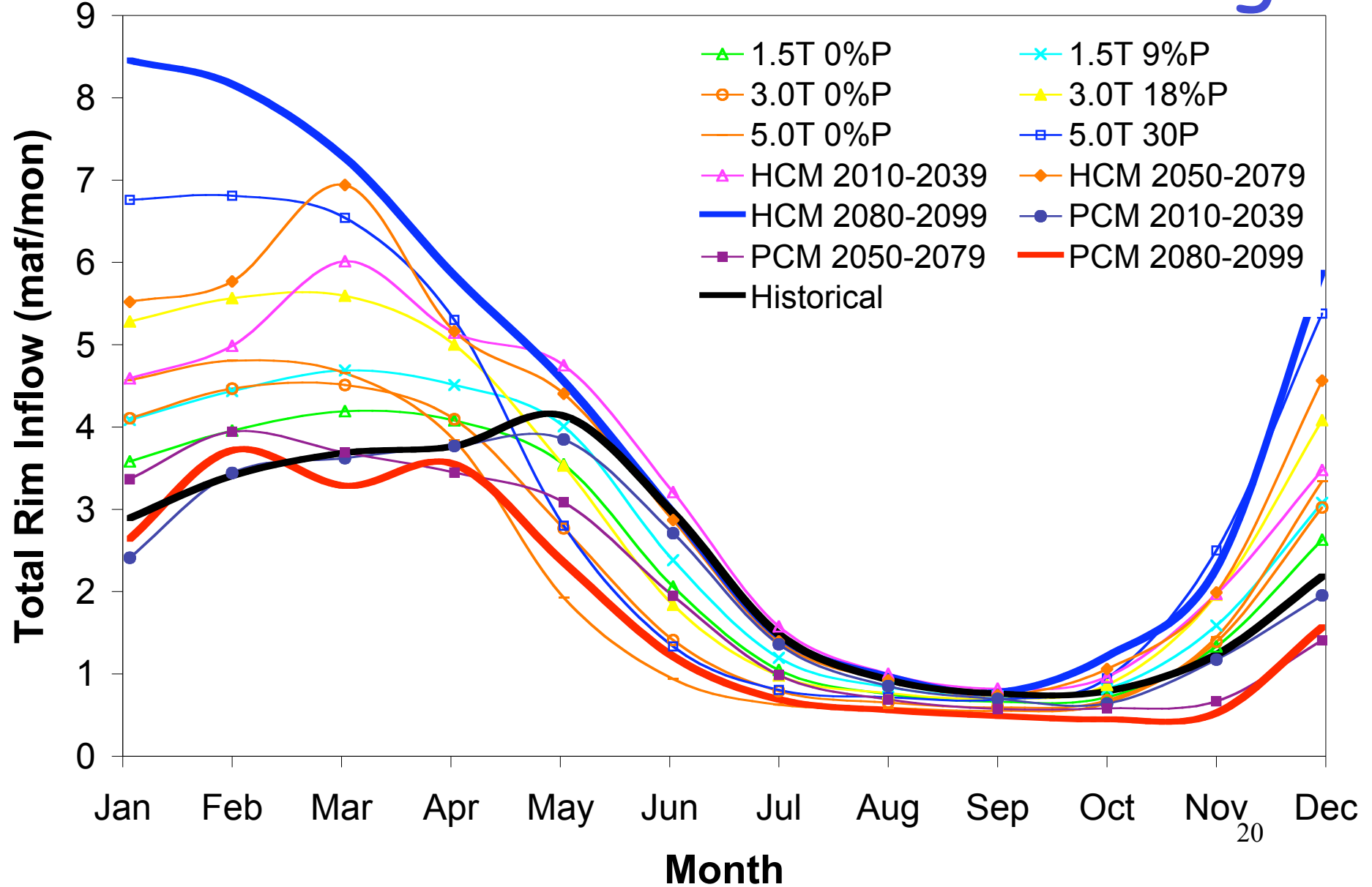
Pia M. Grimes

Jennifer L. Cordua

Matthew Ellis

<http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/>

# Inflows with Climate Warming





# 2100 Water Availability Extremes (maf/yr)

<b>Scenario</b>	<b>Average</b>	
	<b>Availability</b>	<b>Change</b>
Historical	37.8	0
Dry Warming (PCM)	28.5	-9.4
Wet Warming (HCM)	42.4	4.6

# What can we do? - Adaptation

- Coordinated facility operations
- Joint surface & groundwater operations
- Water allocation and markets
- Urban conservation/use efficiencies
- Agricultural use efficiencies and fallowing
- Environmental water use efficiencies
- New technologies
  - Wastewater reuse
  - Seawater desalination

California is rich in management options <sup>22</sup>

# CALVIN Model Coverage

Over 1,200 spatial elements

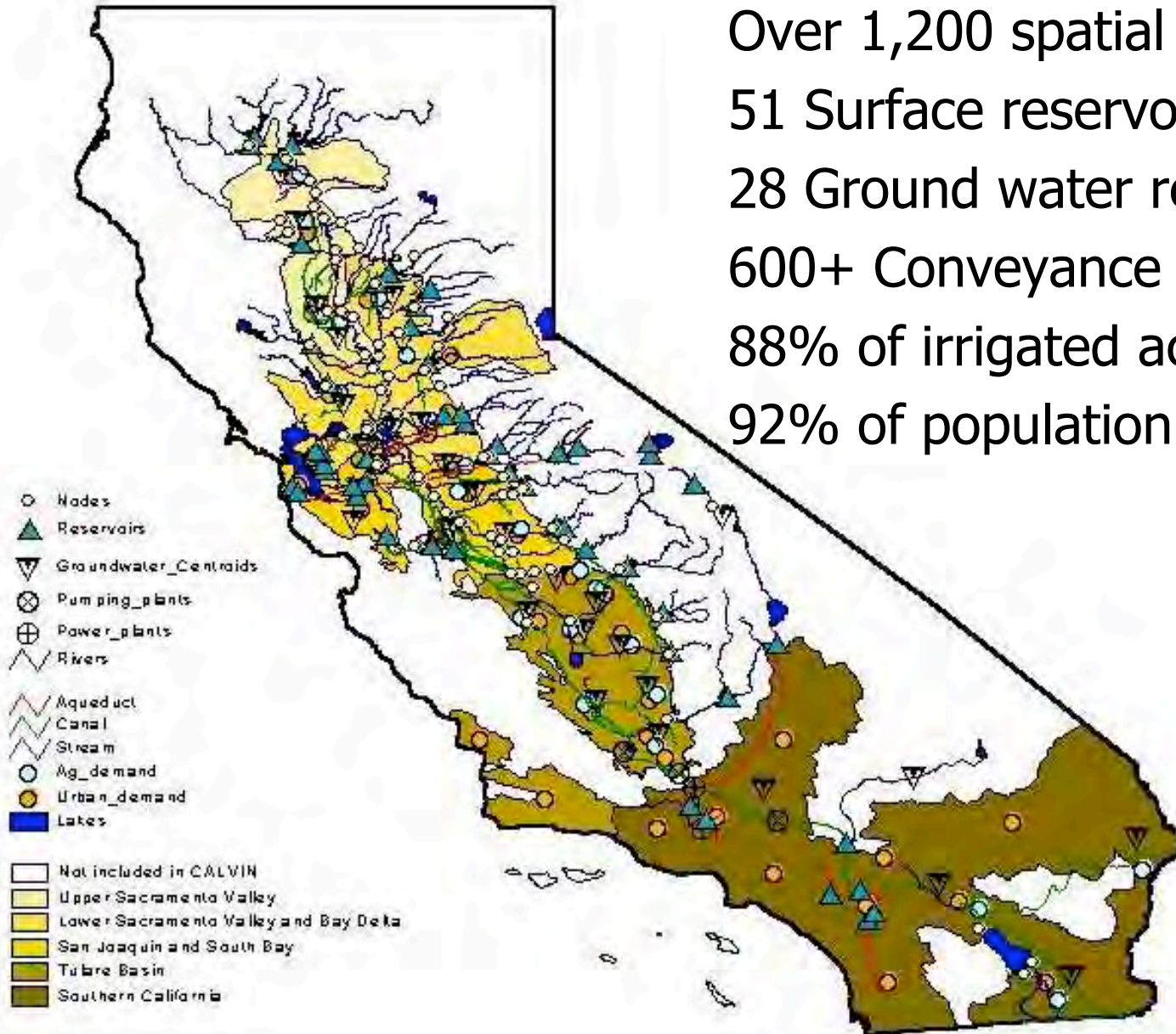
51 Surface reservoirs

28 Ground water reservoirs

600+ Conveyance links

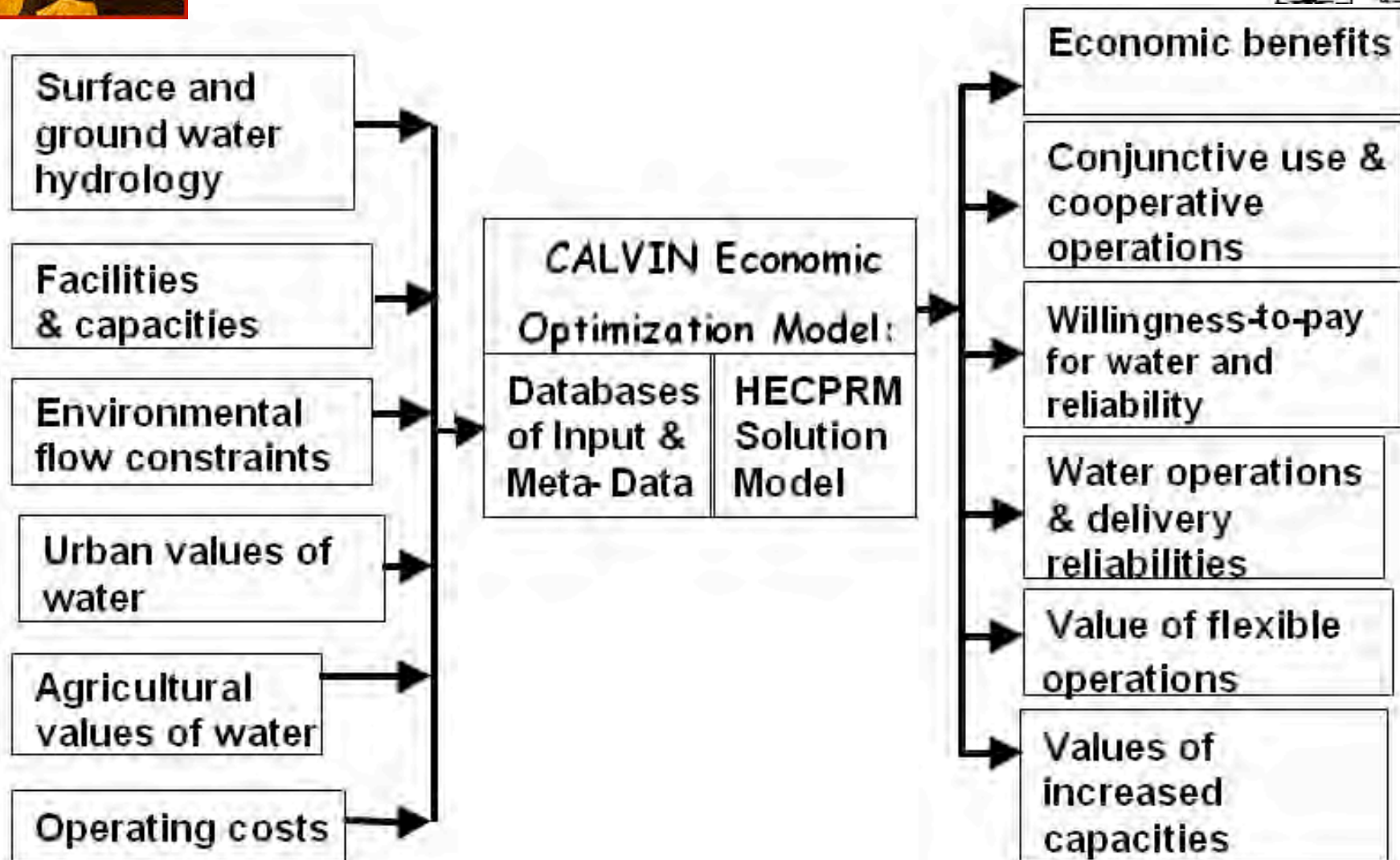
88% of irrigated acreage

92% of population





# Data Flow for CALVIN



# Modeled Adaptation Options

- Water allocation and markets
- Joint surface & groundwater operations
- Coordinated facility operations
- Urban conservation/use efficiencies
- Cropping changes and fallowing
- Agricultural water use efficiencies
- New technologies
  - Wastewater reuse
  - Seawater desalination

# Water Management Objectives

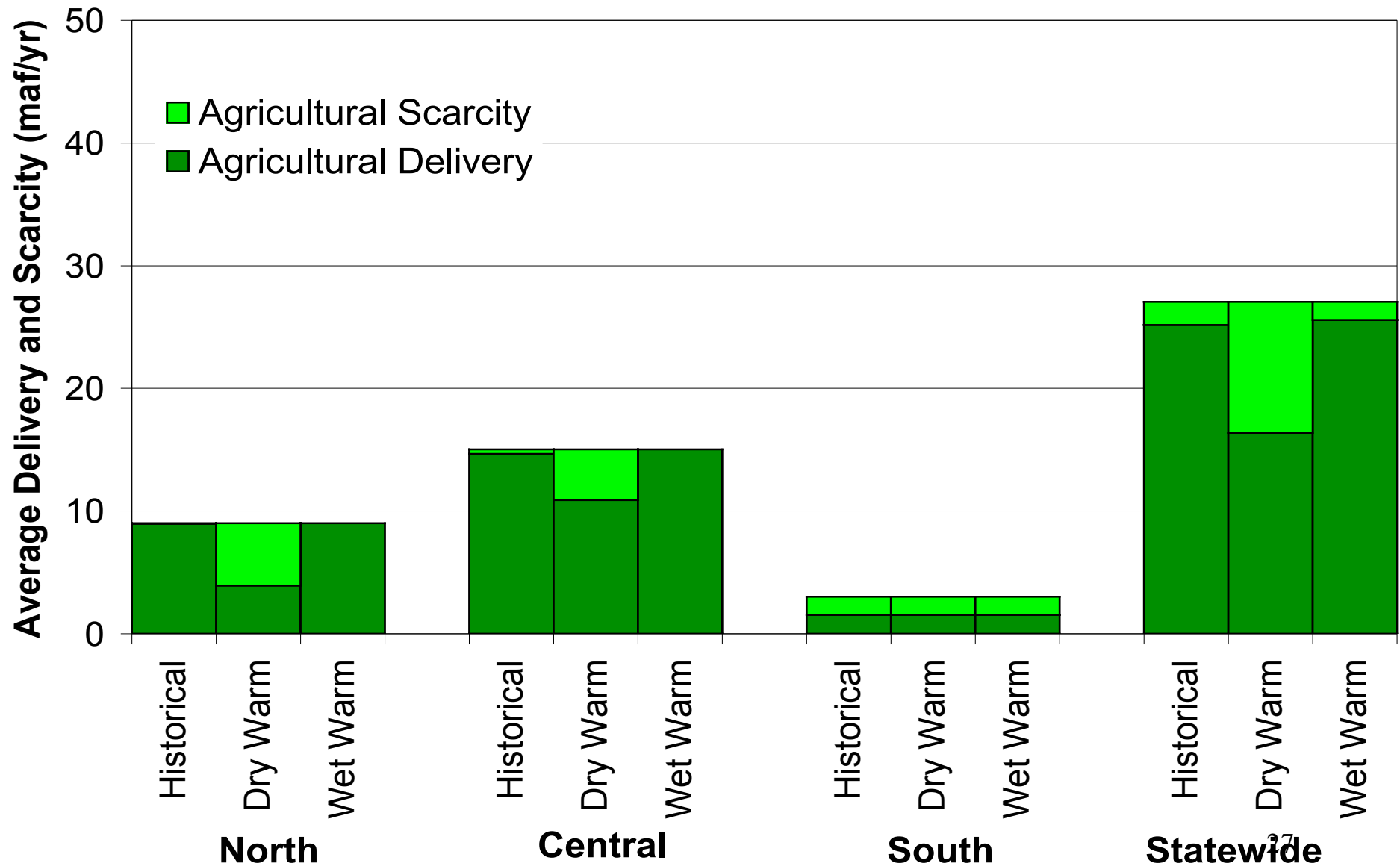
Environmental flows - first priority

Economic Water Uses:

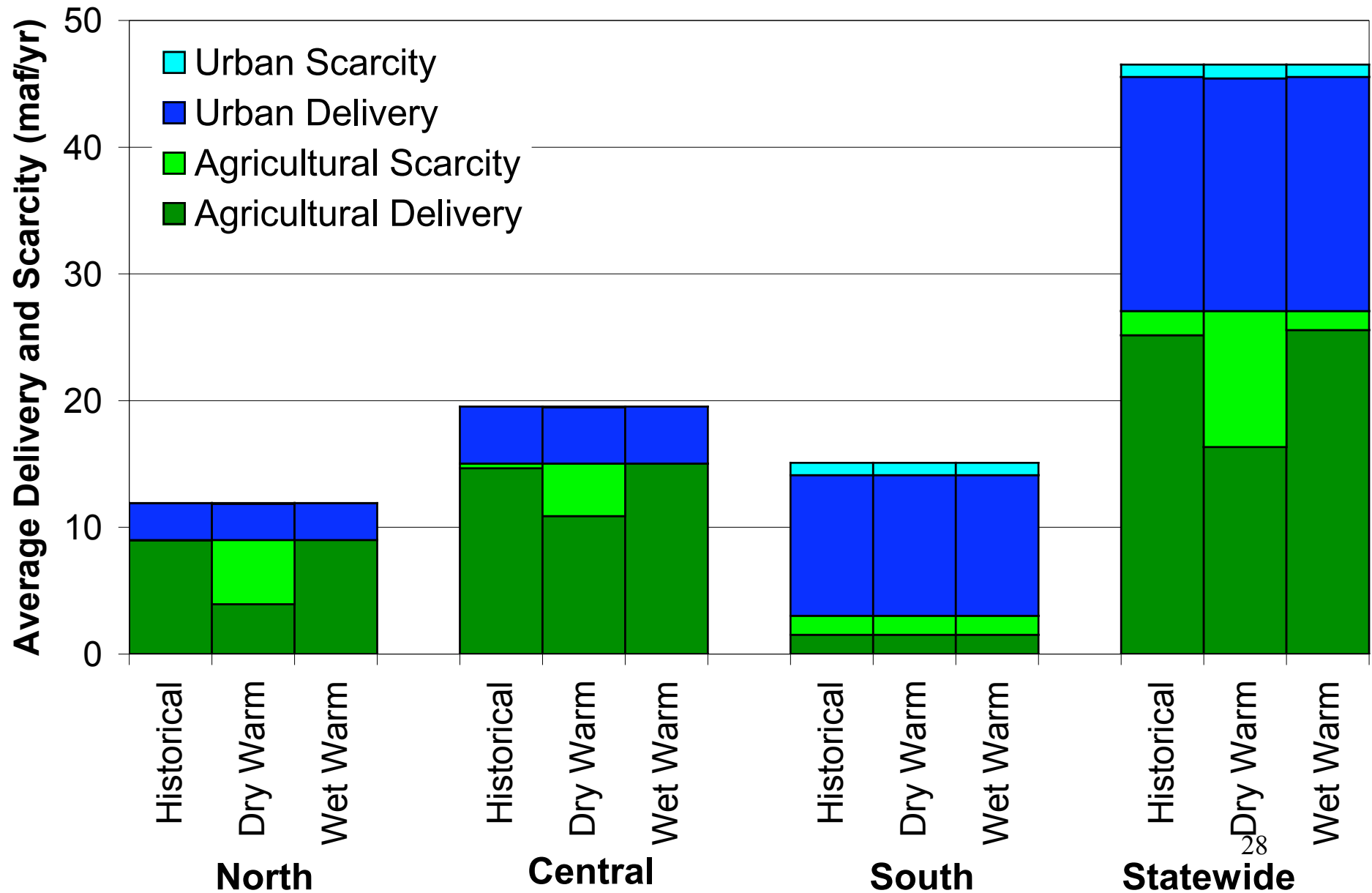
- Agricultural economic values
- Urban economic demands (residential, industrial, and commercial)
- Hydropower benefits
- Operating Costs



# 2100 Water Deliveries and Scarcities



# 2100 Water Deliveries and Scarcities



# Statewide Economic Costs

(\$ million/yr, average)

<b>Cost</b>	<b>Hist. 2100</b>	<b>Dry Warm</b>	<b>Wet Warm</b>
Urban Scarcity Costs	785	872	782
Agric. Scarcity Costs	198	1,774	180
Operating Costs	5,918	6,065	5,681
<b>Total Costs</b>	<b>6,902</b>	<b>8,711</b>	<b>6,643</b>

# Adaptive Responses

- Groundwater storage and conjunctive use
- Water market transfers
  - Agricultural to urban
    - Colorado River
    - Central Valley
  - Water quality exchanges
  - Flexibility trading
- New technologies
  - Wastewater reuse
  - Sea water desalination
- Urban water conservation/use efficiencies

The mix of responses is important.

# Economic Value of Facility Changes

Facility	Hist. 2100	Dry Warm	Wet Warm
<b>Surface Reservoir (\$/AF-yr)</b>			
Pardee	68	202	56
Pine Flat	66	198	56
New Bullards Bar	65	196	56
Los Vaqueros	64	186	53
<b>Conveyance (\$/AF/month/yr)</b>			
All American Canal	7379	7613	6528
Mokelumne Aqueduct	7180	7609	6301
Friant Kern Canal	1733	1960	3585
Colorado Aqueduct	1063	970	759
California Aqueduct	669	1823	452
Hetch Hetchy Aqueduct	489	410	452






# Environmental Flow Costs

(\$/AF)

<b>Minimum Instream Flows</b>	<b>Hist. 2100</b>	<b>Dry Warm</b>	<b>Wet Warm</b>
Trinity River	45.4	1010.9	28.9
Clear Creek	18.7	692.0	15.1
American River	4.1	42.3	1.0
Mokelumne River	20.7	332.0	0.0
Stanislaus River	6.1	64.1	0.0
Tuolumne River	5.6	55.4	0.0
Mono Lake Inflows	1254.5	1301.0	63.9
Owens Lake Dust	1019.1	1046.1	2.5
<b>Refuges</b>			
Sac West Refuge	11.1	231.0	0.1
Volta Refuges	38.2	310.9	20.6
Kern	57.0	376.9	35.9
<b>Delta Outflow</b>	9.7	228.9	0.0



# Conclusions: California Water Supply

-  Climate warming can be wetter or drier overall, with seasonal flow shifts.
-  Optimization needed for large complex systems, with dynamic interdependencies at multiple scales.
-  Agricultural water users in the Central Valley are the most vulnerable to climate warming.
-  California's water supply system, managed well, can adapt well to growth and climate warming.
-  Water markets drive adaptation. Without water market, adaptation would be much more costly.<sup>33</sup>

# Overall Conclusions

## 1) Value of quantitative analysis

- Integrates scientific understanding
- Identify important things we don't know
- Explore options and impacts
- Make discussions more productive

📄① Optimization can explore many options and identify promising combinations

📄① We have only begun to understand water management in California, using numbers